STRATEGIES FOR CONVERTING TO NEW TECHNOLOGIES

Computer Graphics in the Color Printing Industry

Alan K. Graham

David P. Kreutzer

WP-1503-83

STRATEGIES FOR CONVERTING TO NEW TECHNOLOGIES

Computer Graphics in the Color Printing Industry

Alan K. Graham

David P. Kreutzer

WP-1503-83

D-3411-2

STRATEGIES FOR CONVERTING TO NEW TECHNOLOGIES

Computer Graphics in the Color Printing Industry

By

Alan K. Graham
David P. Kreutzer
Sloan School of Management
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Presented at the 1983 International
System Dynamics Conference
Newton, Massachusetts
July 28, 1983

Revised August 1983

ABSTRACT

A number of challenges face firms that need to decide whether and when to convert from traditional technologies to new computer-based technologies. Such is the case with lithographic setup shops, which prepare photos for color printing; they must choose between continuing the traditional craft or acquiring digital image processing equipment. Pioneering firms can be saddled with experimental, undependable, and expensive prototype systems. Rapid technological changes still occurring in digital systems can allow competitors who invest later to obtain cheaper, more effective equipment. But firms investing too late may find themselves paying for the large investment just when most competitors are established in the new technology and competition has forced prices and profits to low levels.

In order to create a framework for developing and analyzing conversion strategies for these firms, we built a system dynamics model of the color prepress industry, its market, and a typical firm. The primary purpose of the model is to provide a clear understanding of the impact such major capital investments in new technologies will have on the profit structure of a firm and to help develop effective conversion strategies. A secondary purpose of the model is to aid the equipment makers in understanding their market and to provide them with a tool for generating alternative scenarios given different assumptions about economic trends, technological developments, prices, market size and composition. The model serves as a strategy support system that allows clients to derive scenarios explicitly from causal assumptions and to evaluate alternative conversion strategies.

The results indicate that there is a "window of opportunity" for converting to new technologies; converting before or after this "window" can place a firm at a considerable disadvantage. The window opens after the technologies become commercially usable. The window closes when the majority of firms in the industry have converted; even though average profitability is still high at that point, there is not enough time to recoup the investment before increased overcapacity forces prices and profitability to drop. The conversion strategies analyzed for the lithographic setup shops apply to several other industries and technologies, including architecture, engineering development, manufacturing, and computer hardware and software development.

STRATEGIES FOR CONVERTING TO NEW TECHNOLOGIES

Alan K. Graham
David P. Kreutzer

Rapid advances in technology are transforming the structure and the nature of many industries, presenting firms with difficult challenges. Boundaries between industries change over time, expanding and shrinking as new applications become available or firms in other industries capture or replace an older industry's market. Sometimes separate industries gradually merge as technologies developed for one industry find applications in new areas. The traditions, strategies, and technologies that firms have developed may no longer suffice to maintain their competitive strength.

Figure 1 illustrates technological changes in the information processing, publishing, and broadcast industries. Originally, each technology was entirely separate; the circles did not intersect. But the industries have been merging gradually, as new products are created that involve the technologies of several industries; so the circles are moving together. The overlap of information processing and broadcast media has produced computer animation systems, character generators for print displays on TV, and satellite broadcast systems. The overlap of publishing and broadcast technologies seems ready to produce videotext services, having already produced information services such as stock market and credit reporting.

The overlap of information processing and publishing produced word processing and automated typesetting. More recently, the overlap of all three industries has produced videodisc technology and digital color image processing for computer animation and for printing, which is the subject of the case study reported here. For a wide variety of businesses the tools of the trade are changing rapidly, due to the diffusion of new technologies from previously unrelated industries.

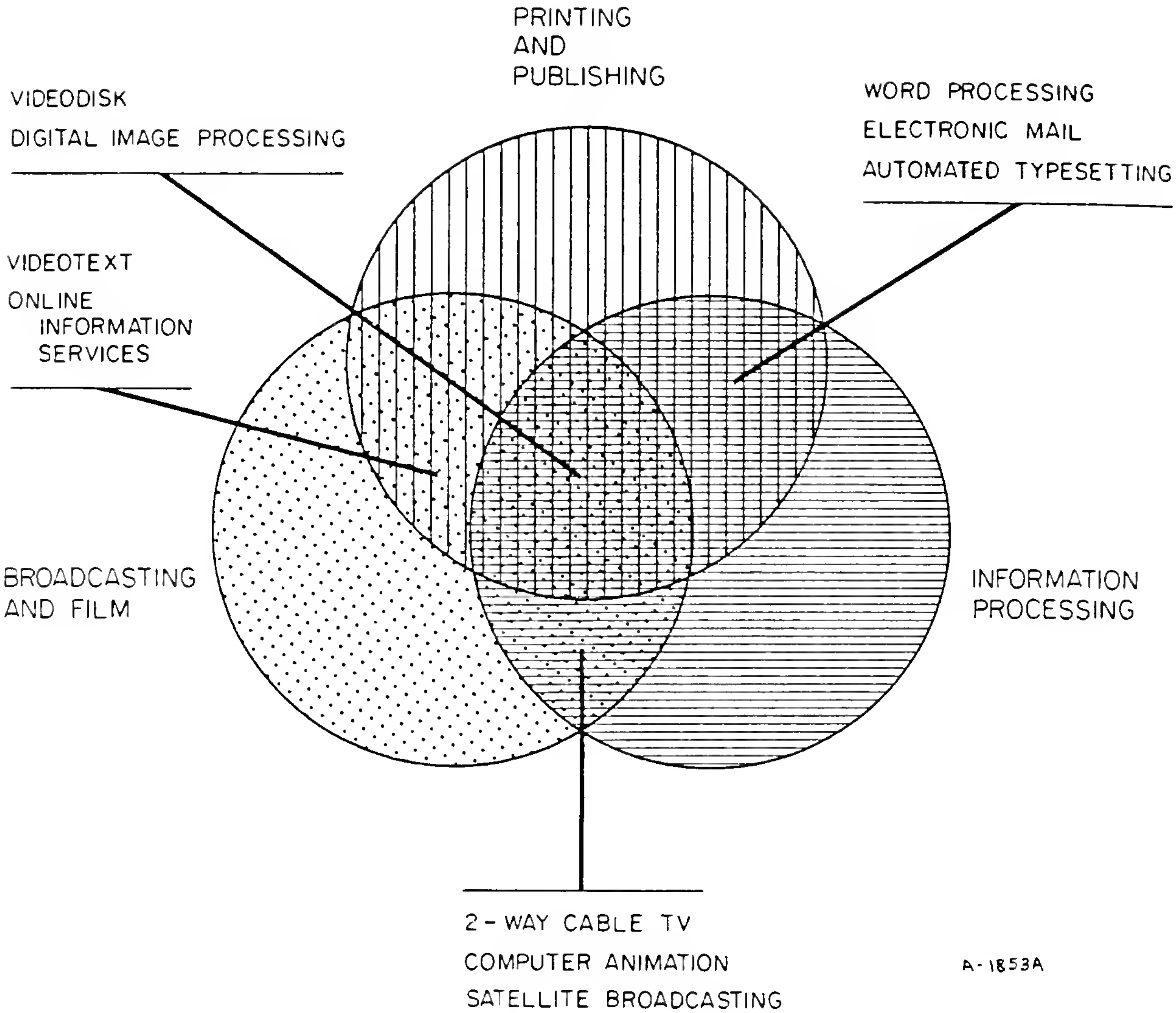

Figure 1. Technological Convergence of Three Industries Create New Applications (after Negroponte and Lippman [1]).

HISTORY OF GRAPHICS IN COMPUTERS

Originally developed for military and space uses, digital image processing has been just one component of the computer technologies that have been diffusing into other industries. The history of digital image processing and interactive computer graphics can be traced back to Jay Forrester's Whirlwind Computer project in the early 1950s, which first used

the computer-driven CRT (cathode-ray tube) display. Another significant development in interactive computer graphics, which occurred during the construction of the North American radar net during the SAGE air defense program (also directed by Forrester), was the use of CRTs as command and control processors. Light pens could be used to touch the image of an airplane or other object on the radar screen causing the computer to track it as it moved through the territory. Since then, digital image processing has been substantially developed by NASA and the Defense Department for guidance systems for missiles, satellite surveillance, and the exploration of other planets.

Computer technology has diffused into many parts of the civilian economy. For decades, accounting in large corporations has been automated. The travel industry has long since converted to on-line reservation systems. However, because of the intensive computation needed to create and modify images, computer graphics technologies have spread more slowly. The first such systems were expensive military flight simulators and specialized applications, such as processing satellite surveillance data. As computing costs steadily diminished over the decades, new applications proliferated to lower-cost systems involving standardized characters for automated typesetting, word processing, and superimposing text on TV broadcasts. The increasing power of computers is now making it possible to compose or manipulate entire images commercially. Today, computer-generated images are common in film, television, video games, and advertising, and they are starting to be used by the subjects of this case study, the companies that prepare color pictures for magazines and newspapers.

The encroachment of computer technology into uncomputerized industries is by no means over. Indeed, many industries face the same "conversion trauma" as lithographic setup shops. Engineering and manufacturing firms face the decisions of when and how to adopt computer-aided design (CAD) and manufacturing (CAM), which may include robots. Architectural firms are

installing computer graphics systems that not only expedite the drafting process, but also check the adequacy of space allowed for ducts and wiring and generate material requirements and cost estimates. Computer firms are also faced with technology conversion questions: when and how to shift to designs using very large-scale integrated circuits [2], or how fast to adopt software development tools, which are computer programs that help produce higher-quality programs faster [3]. Finally, "expert systems"--programs designed to mimic the analysis of an expert in a given field--are beginning to appear in applications as diverse as manuscript editing and seismic oil exploration. All in all, like the color preparation industry, <u>many</u> industries are about to face the trauma of conversion to computer-based production technologies.

THE COLOR PRINTING INDUSTRY

Like the computer industry, the printing industry has a distinct history with its own brand of technology, starting with the Gutenberg press in the mid 1400s. Wooden frames and blocks of movable type were used to press inked images down onto paper. From those printing blocks the highly skilled craft of engraving and lithography developed, where artisans would carve (or etch) their images onto metal plates.

During the last century the traditions and descendants of those craftsmen formed the basis of what is now called a lithographic setup shop or a color prepress preparation shop. These shops produce the film that is now used to photoengrave the printing plates in modern presses. Sometimes they are a division of a printing company; sometimes they are independent. Customers come to them with color photographs and the outline of a page design, for example, for the color-printed cover of a magazine or catalog. These printed color pictures are actually composed of thousands of tiny dots usually printed with only four colors of ink. By juxtaposing these

dots precisely, the eyes perceive the image as containing thousands of hues that subtly and continuously blend together.

The setup shops take the original photographs and text overlays, arrange the page layouts, and produce separate films of tiny dots for each of the four colors so that the final product will resemble the original. These shops also perform image modification such as airbrushing and color changes. The industry is an ideal opportunity for computerization, because these processes are laborious and demand considerable skill.

MERGING OF TECHNOLOGIES

In the past few years computer and printing technologies have come together so that computer image processing can now replace many of the traditional methods in the color printing industry. Many assumptions about the upcoming changes in this industry are widely accepted. Digital image processing is expected to dominate the industry within three to ten years. The reliability and effectiveness of digital processing is expected to increase far beyond that of manual processing as industrial experience with the technology increases. The cost of the equipment is expected to drop as the market and the technology mature. Also, as the cost of the equipment drops and its effectiveness within firms increases, the production costs for the firms with digital equipment is expected to drop sharply.

Given precedents in other new technologies, however, unstable prices are expected for prepress jobs. When the number of units in the field nears saturation, the boost in productivity produces excess capacity, which results in widespread price cutting by firms attempting to gain market share. This drives the average market price toward the new, lower cost per job inherent in digital processing, which reduces the originally higher profit margin--the very same profit margin that is one of the main selling points of the equipment!

The expected changes in the marketplace due to conversion to new technologies pose a challenge to individual firms. Several conversion strategies exist, each of which presents opportunities and dangers. Firms must decide what posture to take with respect to this conversion. Do they want to be pioneers at the forefront who perfect the new technology? Should they wait until after the pioneers have made the major mistakes, determine the solutions, and then go in? Or should they wait even longer, until the technology matures, the market settles out, and little uncertainty remains?

A CASE STUDY: ELECTRONIC GRAPHICS FOR THE COLOR PREPRESS INDUSTRY

In order to develop a framework for the analysis of conversion strategies, we have built a computer simulation model of an industry, a market, and a firm. The model examines investment strategies of lithographic prepress color preparation shops making the transition from traditional manual processing to electronic color page make-up systems. The project was initiated and sponsored by Inter/Consult, a consulting firm for the graphic arts industry.

The primary purpose of the model is to provide a clearer understanding of the impact that major capital investments in new processing technology will have on the profit structure of lithographic setup shops, and to help these shops develop effective conversion strategies. A secondary purpose of the model is to aid suppliers of digital image processing equipment in understanding their market and provide them with a tool for generating alternative scenarios with different assumptions about economic trends, technological development, prices, market size, and market composition.

In a sense, the study reported here is a pilot study. In relation to many modeling efforts, the time span and resources were small. The intended outcome was not to implement a specific policy in a specific firm

(that would come from succeeding efforts), but to demonstrate that substantial insights into the issues can result from modeling using the system dynamics approach.

SYSTEM DYNAMICS

System dynamics is a methodology and a body of knowledge about problem solving that revolves around the use of computer simulation models to test and design policies, much as a wind tunnel is used to design aircraft. Edward B. Roberts, in Managerial Applications of System Dynamics, describes system dynamics more precisely as "the application of feedback control systems principles and techniques to managerial, organizational, and socioeconomic problems [4]." In the seminal text Industrial Dynamics, Jay Forrester explains how the approach "provides a single framework for integrating the functional areas of management--marketing, production, accounting, research and development, and capital investment [5]."

Once a computer simulation model is capable of replicating the historical dynamics of the problem being investigated, a variety of policy tests can be undertaken. The modeler can do experiments with the model which would be expensive or even risky in real life. "What if" scenarios can be simulated to compare how well alternative strategies fare under a variety of possible situations. Finally, new policies, strategies, and corporate structures can be designed to improve the performance of the system.

THE ELECTRONIC COLOR SYSTEMS MODEL (ECSM)

The first version of the Electronic Color Systems Model (ECSM) was working three weeks after the project started. This prototype provided a very useful basis for discussion over the remaining four and a half months

of model development work. The information sources for the ECSM were diverse, as is often the case with system dynamics models. Inter/Consult provided: survey data on installation rates, equipment costs, and the economics of lithographic setup shops; previous case histories of technological change in the printing industry; and interviews with representatives from both setup shops and equipment makers. The information at hand was more than sufficient to conceptualize a model structure and assign values to parameters. The Electronic Color Systems Model (ECSM) contains six sectors. In this paper, only three sectors (summarized in Figure 2 and diagrammed in Figure 3) will be active. The

Sector	Represents
Equipment market	Installed base of electronic color systems (ECSs) and their technological effectiveness.
Market	Digital and traditional jobs compete based on price, delivery delay, and quality. The firm competes for jobs based on its relative price, delivery delay, and quality.
Firm	A typical color setup shop, with digital capacity and an investment capability for digital capacity; it responds to market prices and its own utilization of capacity in setting its price. It also generates indices of costs and profits.
Market size (inactive in simulations)	Low price per job increases demand for color setup work, but effective technology allows larger customers to do jobs themselves, which reduces demand.

Figure 2. Summary of Sectors in Electronic Color Systems Model (ECSM)

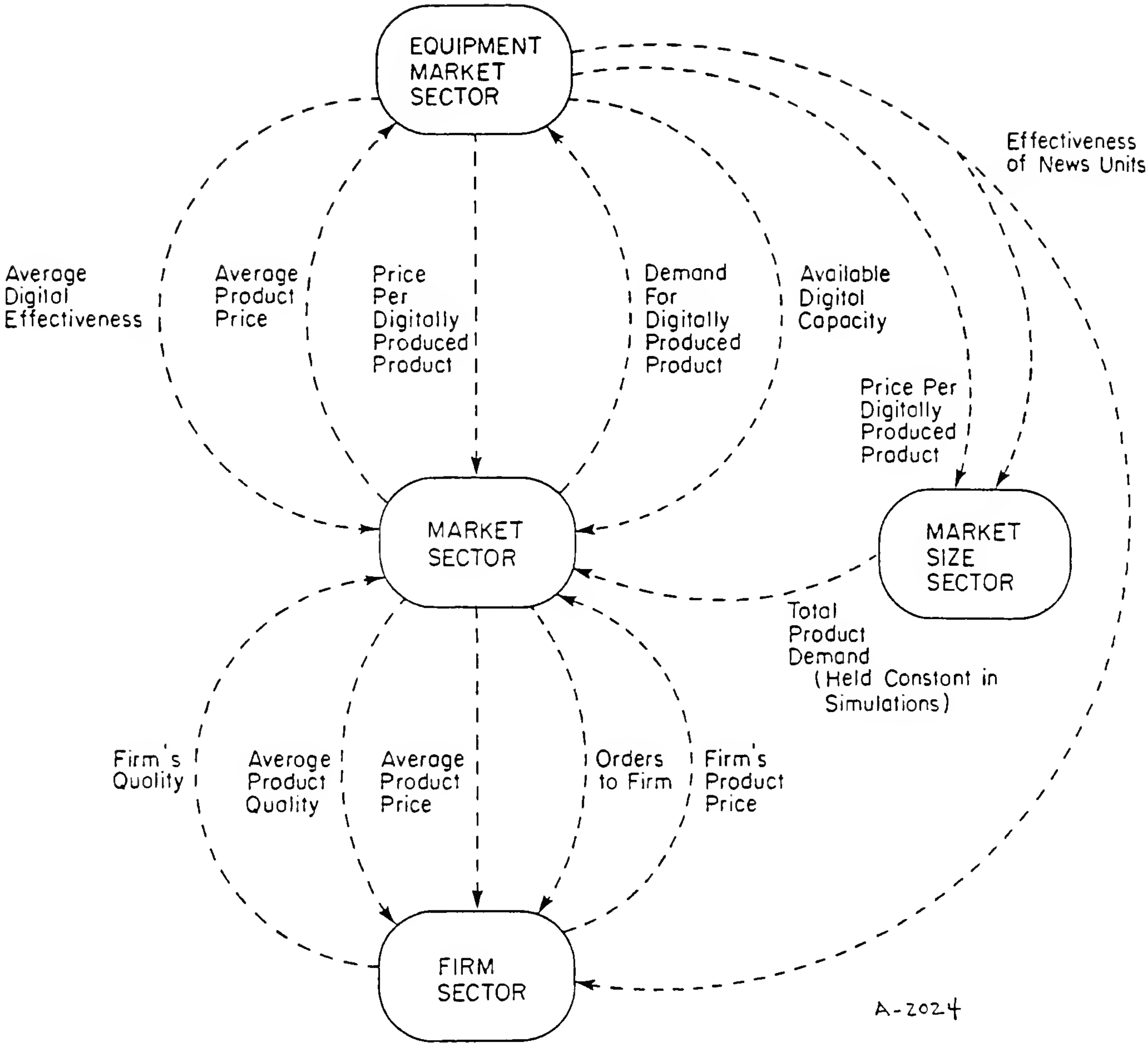

Figure 3. Structural Overview of ECSM

equipment market sector and the market sector represent the environment within which the third sector, the firm, operates. The fourth sector, market size, is held constant in this paper, but is included to illustrate how the sector framework can be elaborated. The remaining two inactive sectors show additional dynamics which are of most relevance to producers of the equipment, when technological advances enable expansion into

secondary markets with less costly devices. That transition is in many ways similar to the successive generations of computers--mainframe, mini, and personal. But space does not permit analysis of such issues here.

Figure 3 is an overview of how the active sectors are interconnected. In effect, the firm sector deals with two markets, the market in which it purchases its production technology (the equipment market sector) and the market in which it, along with its competitors, sells its products (market and market size sectors).

Figure 3 and the later diagrams are interesting examples of the usefulness of computer graphics. Draft versions were produced by a CAD machine. This "art automation" played a significant role during the construction of the model, allowing virtually every discussion with the clients to be accompanied by presentable and completely up-to-date graphics [6].

DYNAMICS OF THE EQUIPMENT MARKET: TECHNOLOGICAL IMPROVEMENT THEN SATURATION

Figure 4 shows a diagram of the equipment market sector. (The model contains more detail than is suggested by the figure; it contains 125 variables and constants, 27 of them in the equipment market sector.) The boxes in Figure 4 represent accumulations or stocks, and the arrows represent flows of information or physical goods. For example, the number of installed ECS units represents the accumulation over time of the installation rate, a flow of units out of the factory and into installation sites.

The diagram is useful not only because it enumerates what real-world phenomena are represented in the model, but also because it shows the interactions that determine behavior as it evolves over time. Of particular importance in system dynamics modeling is the concept of feedback loops: how a decision changes conditions within the system, which

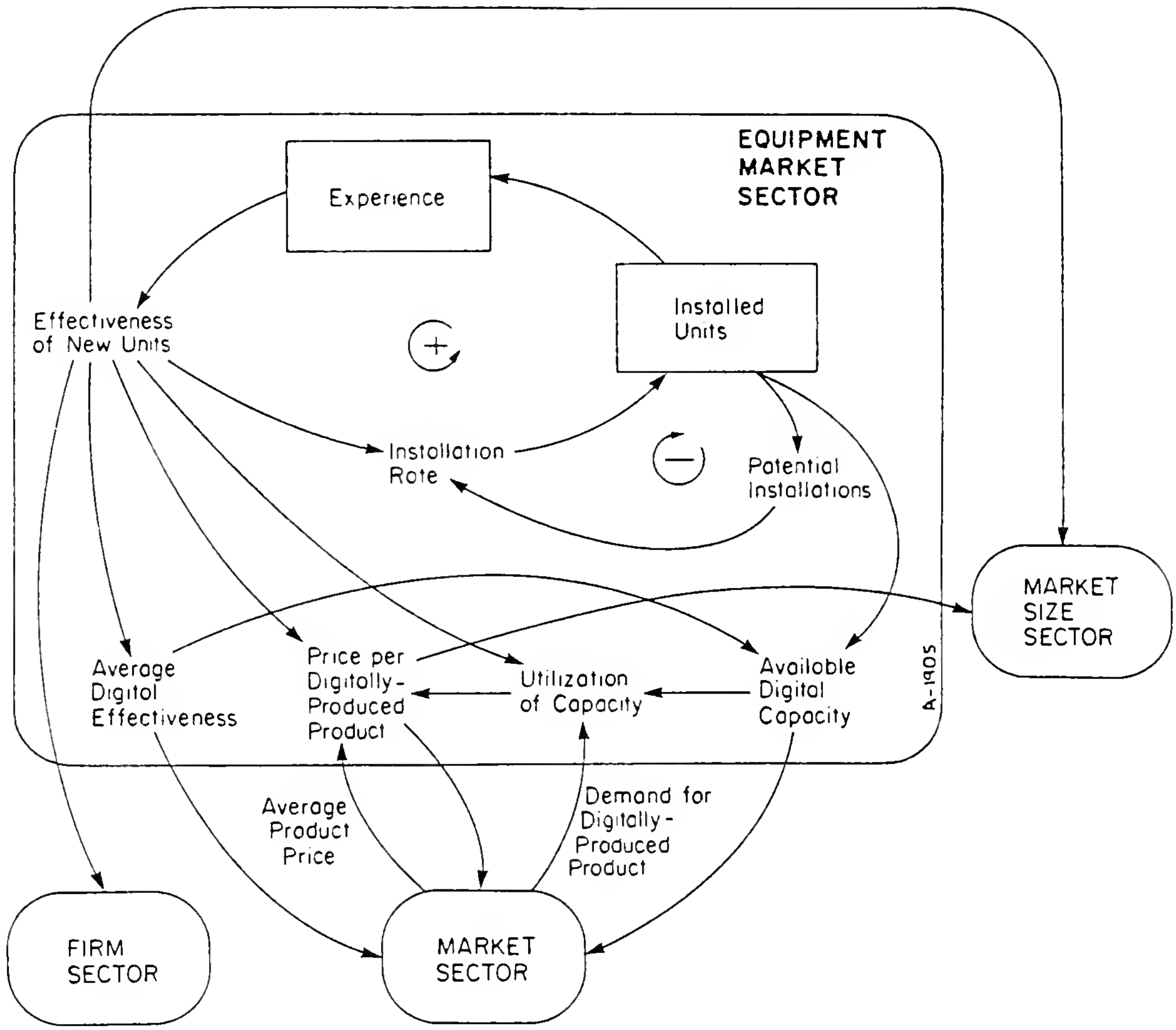

Figure 4. Equipment Market Sector

in turn changes the information upon which subsequent decisions are based. Figure 4 contains only two loops, one positive (self-reinforcing) and one negative (self-correcting). The positive loop connects effectiveness, installation rate, and units in the field. It underlies a version of the classic "learning curve" behavior, where increasing scale of activity leads to technological improvement, which lowers costs and raises effectiveness, which in turn leads to a larger scale of activities.

The model expands on the standard learning-curve/price-decline concept that states that as manufacturing experience accumulates, units can be produced at lower cost, which stimulates sales and adds further to manufacturing experience. But functionality (reliability, capability, ease of use) as well as cost is very important for electronic color systems (ECSs). (The "effectiveness" concept in Figure 4 represents both functionality and price.) An inexpensive machine that is unreliable and difficult to understand and use is not a good buy. Also, technological improvements come more from having units functioning at sites than from manufacturing experience, so that experience using the units accumulates and improves functionality. This experience allows flaws in the hardware and software to be identified and corrected and also permits the designers to determine which features operators need for the system to be effective. Finally, the costs to the manufacturer come down with more units in the field, not so much because of accumulated manufacturing experience, but because R&D costs for software are spread over a larger number of units. (A substantial amount of hardware for ECSs is based on off-the-shelf products of standard computer makers.)

The negative loop in Figure 4 connects units in the field, potential installations, and the installation rate. The installation rate is constrained by the finite size of the market for ECSs. In the extreme, if everyone interested in electronic color systems had already bought one, then sales and installations of new units would be zero. In less extreme circumstances, as most firms install an ECS the paucity of remaining unconverted firms will depress the installation rate. Replacement purchases for obsolete or worn-out equipment are ignored in this case study, because the average lifetime of the equipment is longer than the duration of the industry transition being analyzed.)

Figure 5 shows a simulation of the equipment market sector. As time progresses, operating experience accumulates, leading to improvements in the effectiveness of the technology. As confidence in the technology

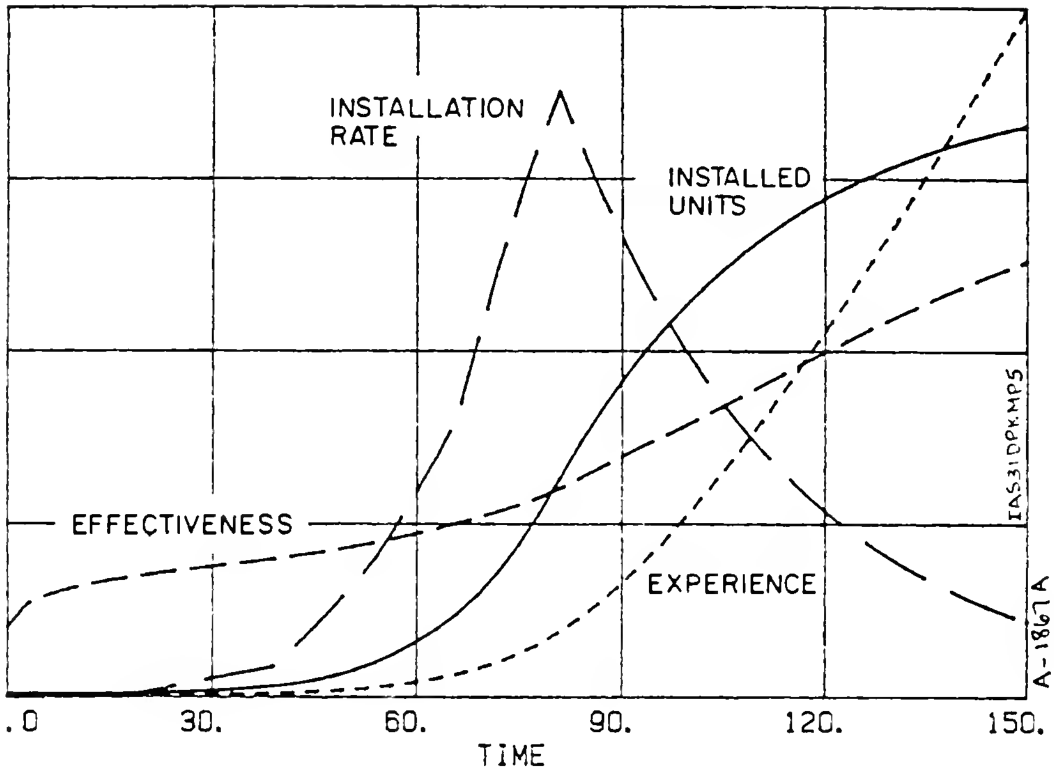

Figure 5. Simulation of Equipment Market Sector

increases, the installation rate increases, thereby accelerating the rate of increase in the effectiveness of the technology. This positive feedback loop alone would produce exponential growth in the units in the field. Such growth happens only during the early part of the simulation, because, as the number of installed units increases, the number of potential intallations decreases. A negative feedback loop is formed that constrains the growth of the industry. So the shift in importance from the positive loop in the beginning to the negative loop after the middle creates the "S-shaped" growth of installed units.

Market saturation--involving not only the S-shaped curve of number of units installed but also the sharply reduced production curve--occurs in many markets. At one extreme of abruptness was the hula hoop phenomenon of the 1950s, where the production curve rose, peaked, and declined within a

year or two. In the middle are autos, whose production rate peaked a few years ago, but for which production continues in order to replace worn-out cars. At the other extreme of abruptness of change is mainframe computers, whose sales are still rising, but at a sharply reduced rate of increase in comparison to earlier decades. (The rapid growth has shifted to mini, micro, and personal computers.) Technological progress is expanding the market for mainframe computers faster (but not much faster) than the market is saturating.

DYNAMICS OF THE COLOR MARKET -- CONVERSION THEN OVERCAPACITY

Figure 6 shows a diagram of the market sector, in which the model represents how supply and demand for color preprocessing influence its price. The market sector also compares the prices and effectiveness of the firm to the market averages to determine the rate at which the firm receives orders. (This will be discussed in the next section.) The market sector can be thought of as mediating between the equipment market sector (and thus the installed digital capacity) and the market size sector (which determines the total product demand, although that is held constant in this paper).

As in Figure 4, the box in Figure 6 represents an accumulation, in this case an accumulation of regular customers, created by ongoing orders to the firm. A self-reinforcing (i.e., positive) feedback loop connects orders and customers: as long as some combination of price and quality is better than the market average, the orders to the firm will rise, the number of regular customers will increase, allowing orders to the firm to continue rising. Conversely, if price and quality combined are inferior, the firm will steadily lose customers over time.

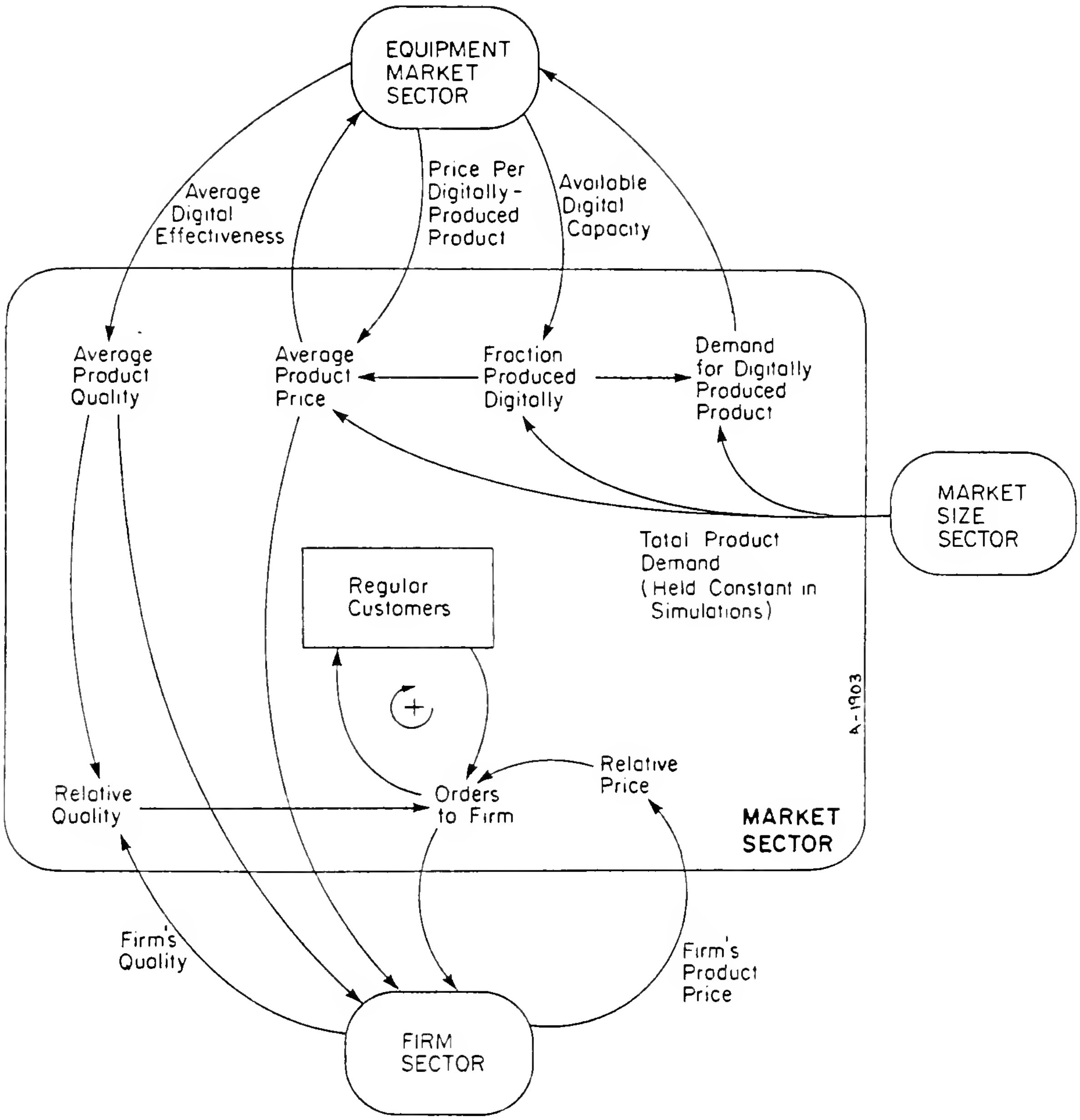

Figure 6. Diagram of Market Sector

Figure 7 shows more variables from the same simulation that created Figure 5. The figure here shows how the product market (for color prepress work) changes over time. (The behavior of the individual firm will be examined in following sections.) In the beginning, when only a few pioneers have electronic color systems, the demand for color prepress work

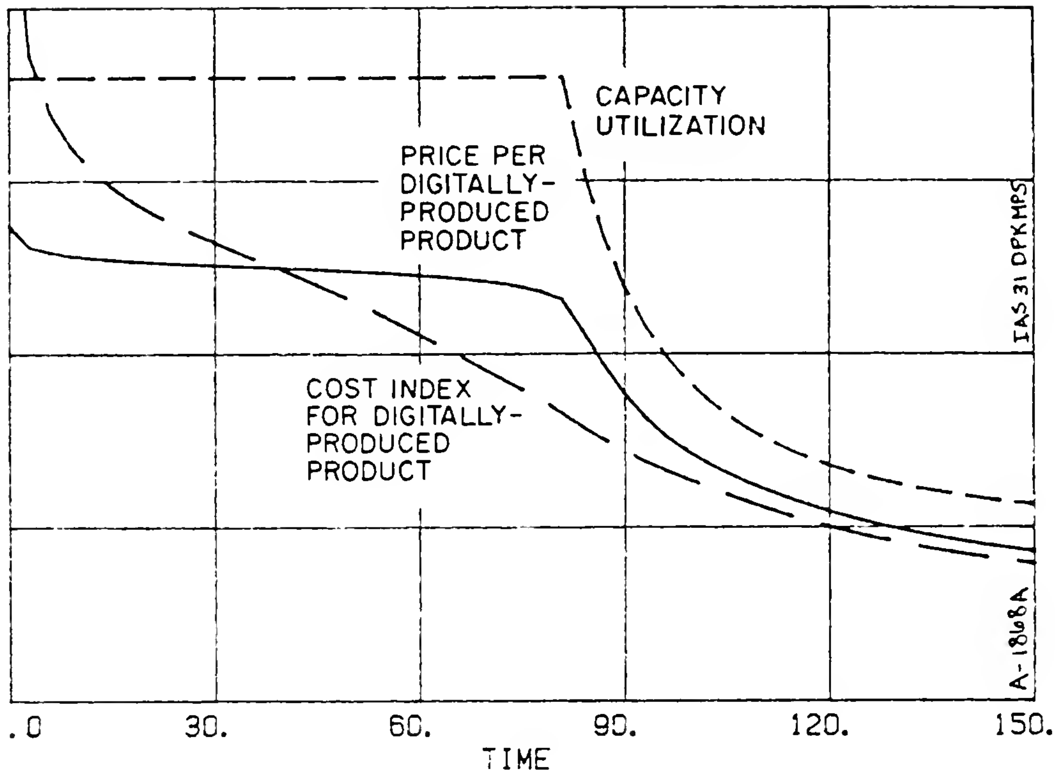

Figure 7. Simulation of Market Sector

is roughly equal to the supply, and the price per digital job is very close to the average market price (even though the cost per job for digital processing has already dropped much lower than the cost per traditional job). There is only slight motivation for those with digital systems to reduce their prices: the digital price is slightly lower than the average market price, because the trade shops with new installations are building up their order rates to their new, higher capacity.

By the middle of the simulation, the cost of electronic color systems is dropping (as modeled in the equipment market sector) and the number of installations is increasing exponentially. There is a period from month 40 to month 80 when the digital production cost has dropped substantially, but price has not; converting to the new technology during this period shows

promise for high profitability. But when the fraction of jobs done digitally approaches its maximum, which it reaches by month 80, excess capacity begins to spread throughout the industry.

This initiates pressures causing price cutting and shakeouts that are prevalent in many industries. Since firms cannot remain cost-competitive without the new technology, many remaining firms convert even after excess capacity pervades the industry. As more firms convert, excess capacity gets worse, increasing pressures to cut price, which in turn pressures the remaining firms to convert. This positive feedback loop is exacerbated by the long delays from the decision to convert, to ordering, delivery, and finally to bringing new equipment up to full capacity.

The growing pressures to add capacity can be seen in the automobile industry. The Japanese carmakers had attained a substantial lead in manufacturing technology and began to increase their share of the U.S. market. This created overcapacity among U.S. makers and the difficulties at Chrysler. But more recently, the U.S. makers have both improved their product and made manufacturing more efficient. The result was <u>more</u> worldwide overcapacity and price cutting. The same sequence of events contributed to worldwide overcapacity in the steel industry, except that not only U.S. steel makers, but also those in Korea and other developing countries have been attempting to out-modernize Japan.

It should be noted that there are several ways for a firm to stay in business while avoiding a direct conversion to digital technology. Because the color prepress industry relies on extensive personal contact with publishers, firms that have already converted successfully may either buy out unconverted firms or take them on as junior partners to act as marketing organizations for the firm with digital capacity. Also, there will be room in the industry for a few traditional firms to specialize in jobs that are inappropriate for digital systems.

Alternatively, firms with excess digital capacity may accept jobs from other firms at lower than manual cost. The part of the electronic color system (ECS) that converts photographs to digital information is much less expensive than the part that performs image modification. As a result, many firms own the former (the "scanner") without being able to purchase the latter. But as scanners become able to transmit the digitized information over telephone lines, many retail shops can send their jobs to a single wholesale firm with a full ECS. Such developments have already begun in architectural firms converting to computer-aided design (CAD) systems: many unconverted firms are sending substantial portions of their detailed work to firms with CAD systems to retain aristic control but take advantage of the quick turnaround and high quality of CAD work. A national chain of computer-generated color slide services has developed using the same communications technology.

So the market sector shows three phases in its evolution: immaturity (where the technology does not have the cost-effectiveness to be used widely), transition (where the cost of using the new technology has dropped but prices have not), and maturity (where capacity excess leads to widespread price cutting and low profits). These three phases seem to define a "window of opportunity" centered around the transition period for converting profitably to the new technologies. The dimensions of this window will be explored by simulating a firm converting at various points in time.

THE FIRM SECTOR AND POLICY ANALYSIS

The sectors just described provide the changing background against which to test the consequences of the different strategies an individual firm might use to make the transition to new technologies. Figure 8 shows a diagram of the firm sector, which represents the policies and conditions within an individual firm: digital capacity, effectiveness

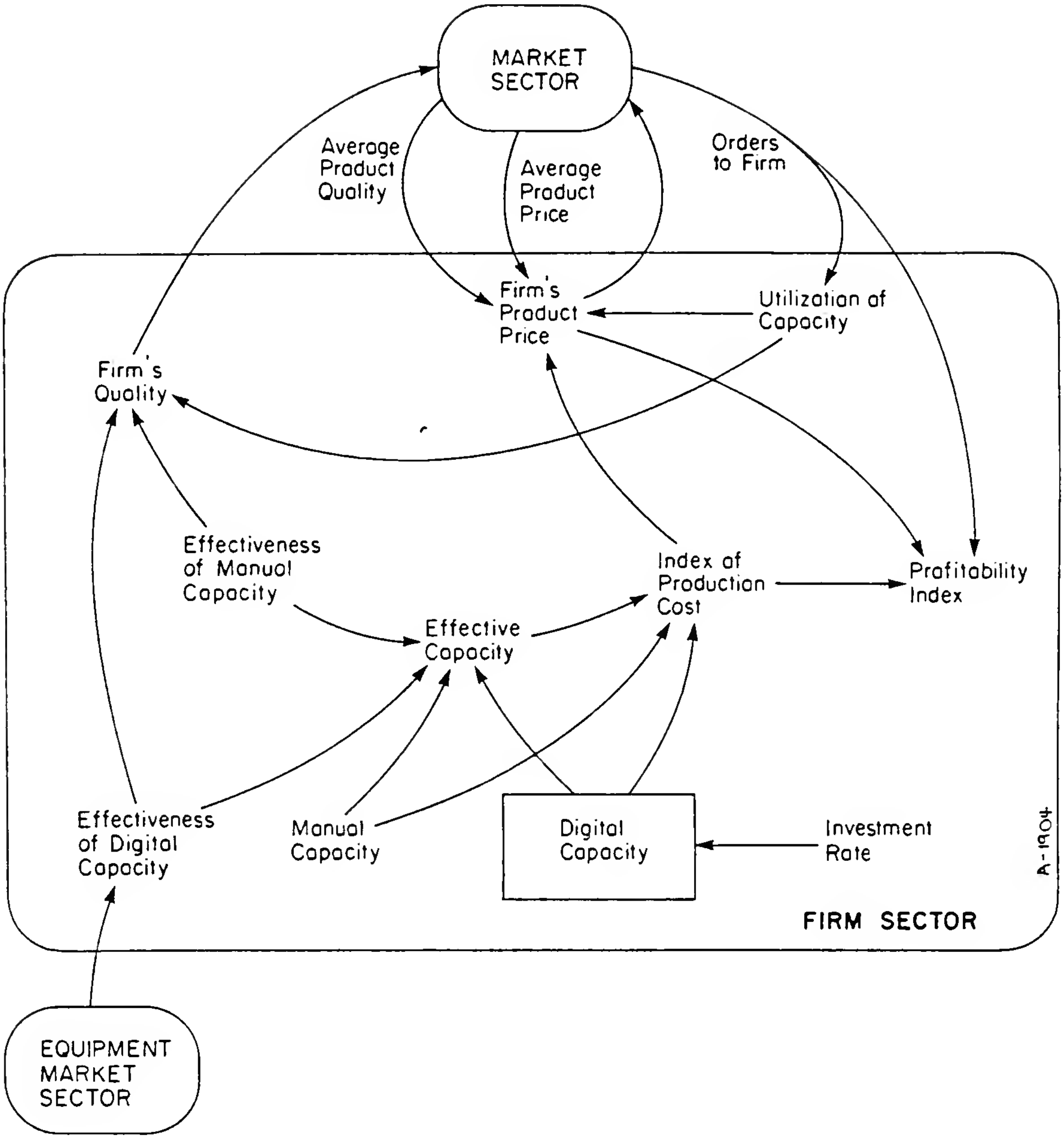

Figure 8. Diagram of Firm Sector

and utilization of capacity, work quality, price and indices of cost and profit.

The following sections describe scenarios generated by the model. One way the model can contribute to strategy development is to provide clear

pictures of the industry's behavior patterns the firm is likely to encounter. The model will only generate behavior that results from a consistent and explicit set of assumptions about causes and effects, and those assumptions along with the behavior can be examined for plausibility--an additional "reality check." The model scenarios follow demonstrably from the present time. By contrast, with a static, mentally generated scenario, one can have little confidence that there exists any plausible sequence of events that would bring the scenario into existence. One can easily imagine, for example, a world in which everyone is superbly educated and productive enough so that no one starves. While this is an inspiring scenario, its most important aspect is missing--how do we get there from here?

The model also offers a tool for evaluating different transition strategies a firm might adopt. For example, all of the simulated investment strategies for the firm are evaluated in the same market environment. The results for the firm, however, depend heavily on the conversion strategy chosen.

EARLY COMMITMENT--IMMATURE TECHNOLOGY REDUCES PROFITABILITY

One conversion strategy that might be explored by an aggressive firm wishing to jump ahead of the competition is to buy the newest, most sophisticated equipment at the first possible moment. If the equipment is functional, the firm can realize substantial profits, as it charges traditional prices while its processing costs are reduced.

However, if the technology is immature, conversion and operating costs can be enormous. Often, the high initial cost of the system will not be repaid rapidly, because the machine is not fully utilized. Newly developed systems sometimes stop working for mysterious reasons, and, surprisingly often, a new system will sit in the corner unused when a firm is too busy

to expend the manhours to learn to operate it. The problem is compounded if the system's educational materials haven't been extensively field-tested and aren't yet effective. Additionally, if a firm is locked into equipment that will become obsolete, the firms that wait before buying will eventually put the pioneering firm at a competitive disadvantage by using cheaper, more effective equipment.

Figure 9 shows a simulation of the early investment strategy, where the firm buys an electronic color system (ECS) in month 2. Production cost rises at first, representing inexperience using and managing the new ECS. As experience accumulates, costs drop, but only to a fixed floor: A critical assumption of this simulation is that the equipment is "locked into" its original level of technology, i.e., there is no increase in its effectiveness as the industry gains experience with digital technology--no annual software updates, for example. Immature technologies may not have

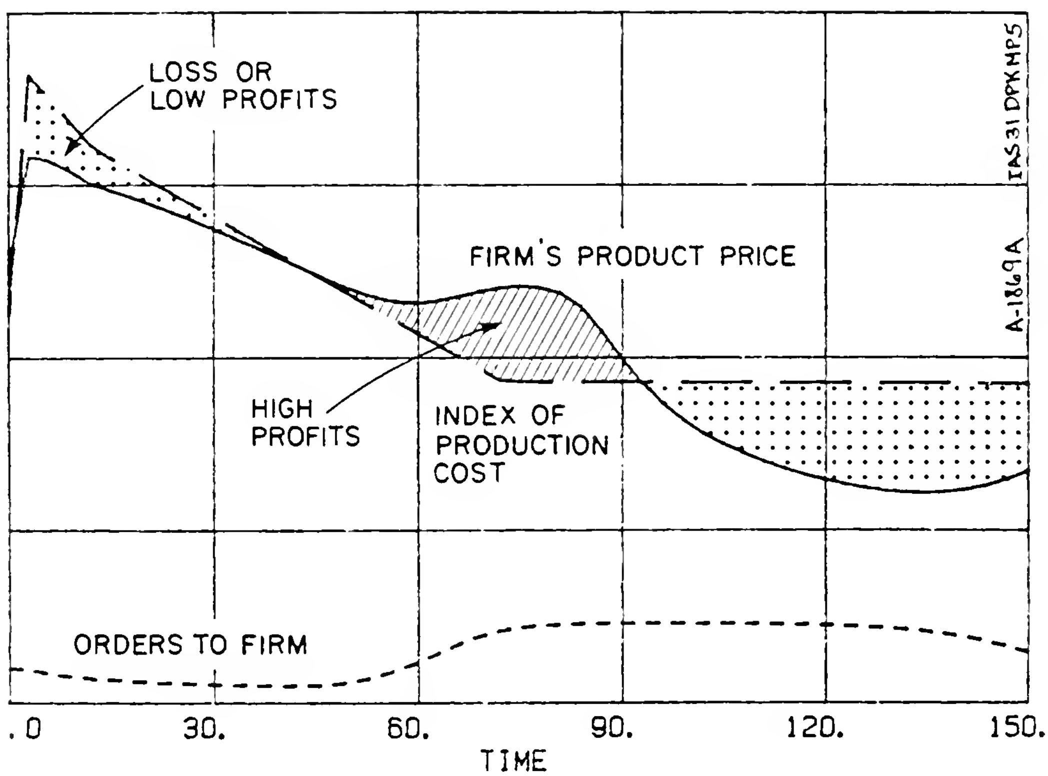

Figure 9. Simulation of Early Commitment Strategy

evolved enough standardization to make such flexibility possible. The firm is committed to the early technology.

The firm's investment in new technology begins to pay off at month 45, when the firm has learned to utilize the new technology, and the firm's index of production costs falls below the prevailing market price. But this period of high profitability is short-lived, for widespread overcapacity drives prices down. And because most of the industry converts later than the firm did, their equipment is more cost-effective; the drop in price will hurt the firm more than the industry as a whole. In terms of a window of opportunity, the firm invested too soon.

LATE INVESTMENT--TOO CLOSE TO SHAKEOUT TO RECOUP INVESTMENT

The firm could wait until the technology matures. This strategy avoids the danger of being locked into immature technology. The risk, however, is that the companies which have already converted successfully will force the traditional firms out of business by reducing their prices to their new lower costs when excess capacity develops in the industry. If the traditional firms survive the price transition and then invest, slender profit margins and erratic cash flows can make financing the equipment both burdensome and risky.

Figure 10 illustrates the late investment strategy with a simulation that delays digital acquisition until month 110. (This and following simulations are drawn to the same scales used in Figure 9, so all are directly comparable.) The late investment strategy avoids the early lock-in effect. The equipment purchased is excellent and embodies a lower processing cost as well as an ability to incorporate some of the subsequent technological advances. However, the firm has also missed the window of opportunity. It is still paying the extra conversion cost when prices are pushed to the new cost floor by those firms that have already purchased advanced systems and payed for them when their profits were

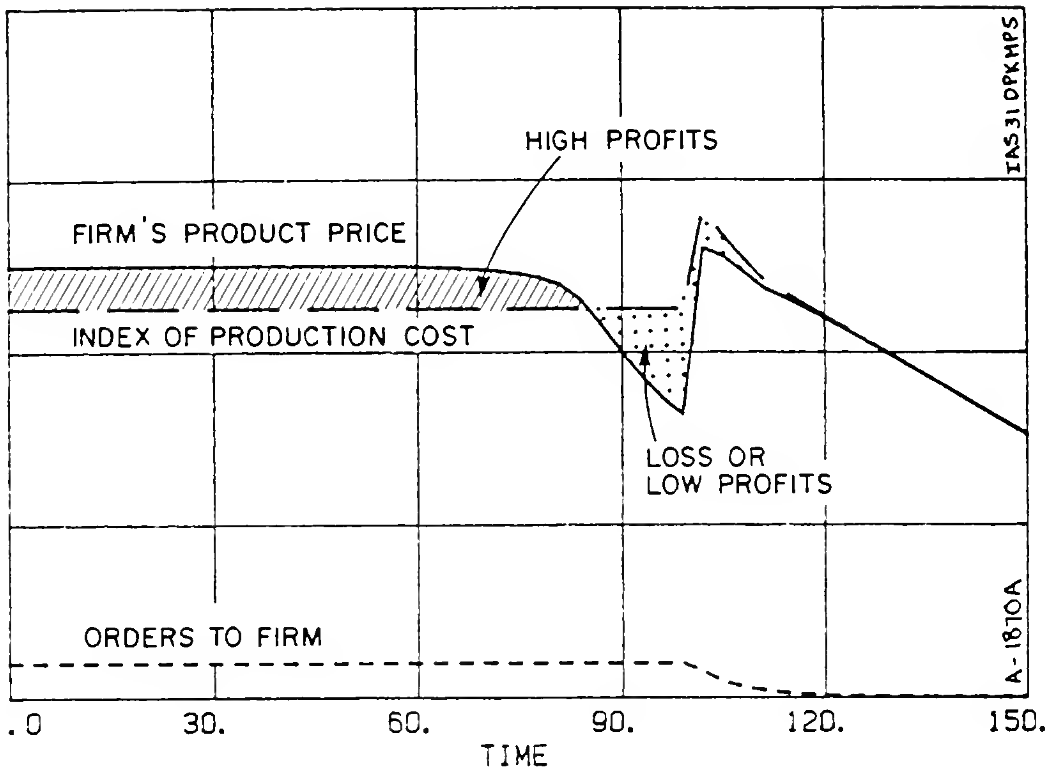

Figure 10. Simulation of Late Investment Strategy

higher. Note that the firm invests when there are still apparently good profits to be made; the price has just barely begun to be forced down by the burgeoning excess capacity of the industry. Such late investment misses the window of opportunity not because of the immediate profit picture, but because the price/cost gap will close before the investment can be recouped. At best, then, the late investment strategy keeps the firm in business. Depending on the smoothness of its conversion costs and the competitiveness of the market, it may not even be able to do that.

GOING THROUGH THE WINDOW OF OPPORTUNITY--A SUCCESSFUL CONVERSION

If investing too early locks a firm into obsolete equipment with high conversion cost and investing late forces the firm to endure conversion costs while the industry is cutting prices, then a strategy somewhere in between may be promising. A moderately aggressive firm whose managers

watch the evolution of the equipment technology closely might take advantage of the policy of some equipment makers of regularly enhancing the software and making new, add-on equipment available. Regular technology updating avoids, to some extent, the problem of older equipment being locked into early technology. So, technologically sophisticated firms may wish to invest earlier than other firms in order to acquire expertise and new customers in hopes that the "updatable" equipment will remain competitive. Firms investing after the pioneer stage of the industry are also able to convert more quickly because the skilled labor and experience of the pioneers are available.

Figure 11 illustrates a highly successful conversion strategy by a firm purchasing digital equipment at month 30 just as the window of opportunity is opening. After recovering from its conversion costs by

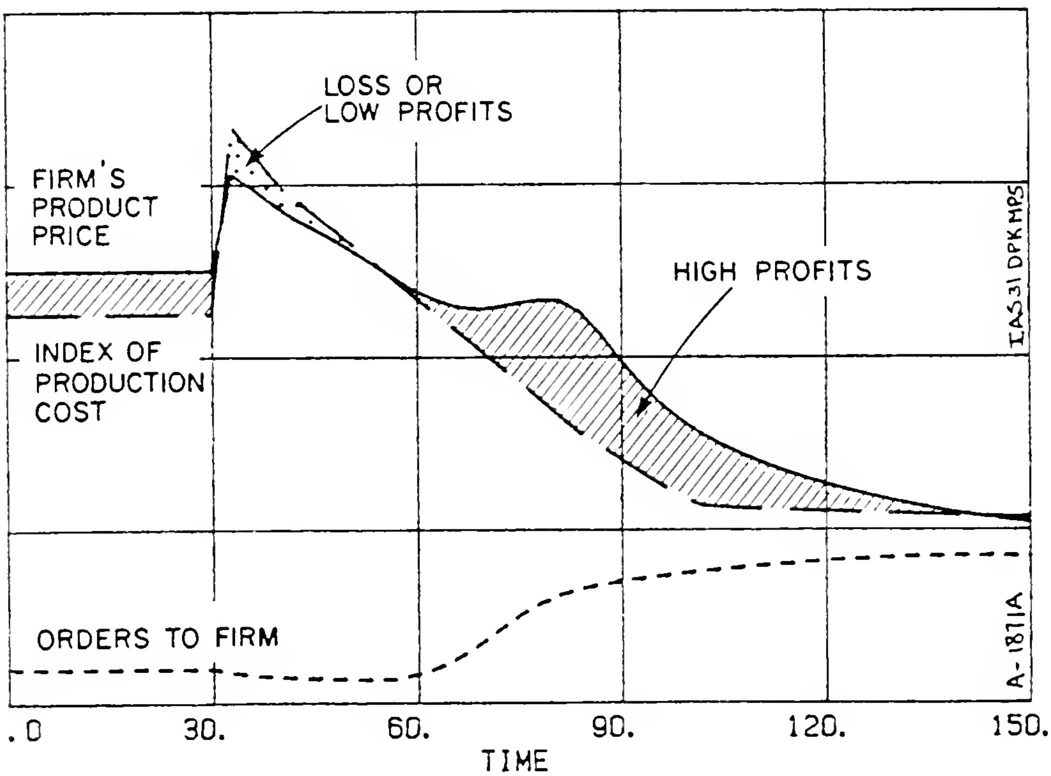

Figure 11. Simulation of Investment During Window of Opportunity

month 60, the firm's operating costs continue to fall until month 110 as it continues to take advantage of improved efficiency due both to the equipment supplier's and its own learning curves. This allows the firm to retain its exceptional profit margin and expand its customer base even as prices are falling.

With no additional investment even this successful firm losses its competiveness by month 140, as it is no longer able to keep up with the most highly advanced systems available during the ninety months following its investment.

INCREMENTAL INVESTMENT--HITTING THE WINDOW OF OPPORTUNITY AND FOLLOWING THROUGH

The firm that invested successfully just as the window of opportunity was opening has another opportunity available to it. That is, to follow through with additional system purchases or major expansions with profits from the first conversion. This incremental investment approach is perhaps the most attractive of the investment strategies discussed here. A firm might purchase an electronic color system with limited features, then add workstations, scanners, and sophisticated software packages as its experience and order rate grow. These major expansions and new systems improve a firm's capability much more than the enhancements and upgrades to an already existing system discussed in the previous section. For this strategy to be effective one must assume that newer systems will be compatible with older ones and that operator skills will be transferable.

Figure 12 illustrates the incremental investment strategy, in which the firm purchases digital equipment at month 30 and additional digital equipment once every fifty months after that. In effect, this is a policy of trying to keep one step ahead of obsolescence. The three investments have quite different effects on the firm's competitive position. The first investment is the entree into electronic color systems; it provides

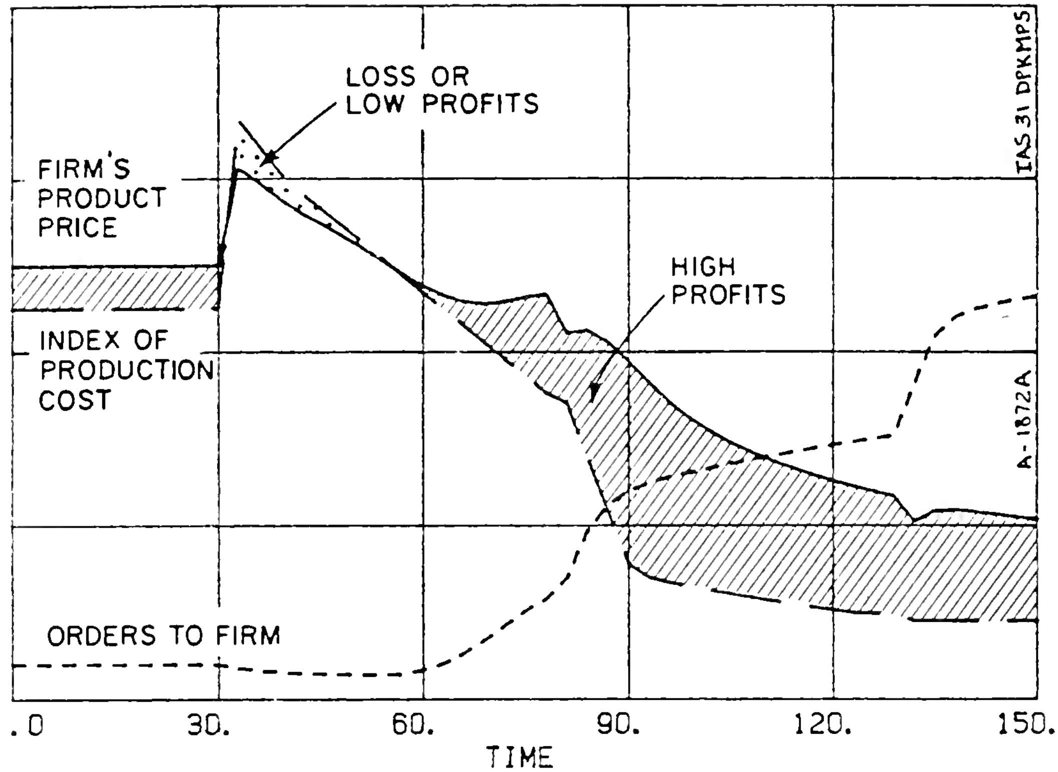

Figure 12. Simulation of Incremental Investment Strategy

experience and begins to build order volume. Profits are substantially improved, until improvement in ECS technology and price cutting begin to threaten profits. The second investment remedies the situation by assuring that the firm's cost after the transition will be as low or lower than its competitors' costs. The third investment does not provide additional technological or cost advantage, but does continue to expand the size of the firm--revenues expand even after an era of price cutting.

By constantly increasing its own effectiveness, the firm remains competitive with increasing effectiveness and decreasing price industrywide. The run shows that the firm's constant price cutting leads to ever-increasing orders.

There are a number of ways a real firm can attract business as its capacity expands. One, of course, is to attract customers one at a time

with more favorable pricing and superior service. Others involve taking over unconverted firms and their customer bases either through outright ownership or through various forms of subcontracting to the unconverted firms, which in effect become purely marketing organizations.

Naturally, there are pitfalls to continual expansion. For example, technology for developing photographs advanced to the point where chains of specialized shops using small developers could promise overnight developing. One of the more prominent chains went bankrupt when, after taking an unexpectedly long time to build up a customer base, its cash commitments to expansion exceeded its revenues, which were already depressed by the state of the economy.

The incremental investment strategy extends the concept of the window of opportunity for the case of multiple investments. The previous sections have shown simulations of a firm making a single investment. For these cases, the window of opportunity is fixed and depends on the dynamics of the equipment and market sectors. But incremental, multiple investments can effectively extend the window of opportunity. The incrementally investing firm makes its final investment at month 110, which produces both a larger volume of business and sustained profits. Yet by contrast, the early-committing firm simulated in Figure 9 shows large losses by month 110. A real firm showing such losses would have difficulty borrowing for a new investment at month 110. The window of opportunity is widened for the incrementally investing firm by timing the earlier investments correctly.

CONCLUSION

The scenarios analyzed here indicate that the best strategy is to convert during the window of opportunity, either for a one-time investment or for starting a series of investments. This result may seem trivial at first glance, in that the best strategy is a compromise between two

extremes: not investing too early, which avoids unworkable and expensive equipment, and not investing too late, which avoids trying to repay the investment during a market shakeout. But the triviality is more apparent than real, for two reasons. First, the model provides specific characterizations of what to look at to determine where the industry is relative to the window of opportunity. The opening of the window occurs when only a few other firms are effectively utilizing the new equipment--well before the opportunities for converting become widely known and compelling. The window for profitable investment is already closing when a substantial fraction of firms in the industry have converted--well before the shakeout arrives. So the analysis here should enable firms to perform better than they would by just responding to obvious pressures.

The second reason that the results are nontrivial is that they apply to a much wider range of circumstances than are simulated here. For example, the market sector is shown in Figures 2, 4, and 6, although it is inactive. When activated, it represents demand for color printing setups increasing in response to lower prices, and also large customers for color setups buying their own electronic color systems (when the technology becomes effective enough), thereby reducing the demand for color setups by lithographic setup firms. These two effects oppose one another; for a relatively broad range of parameters, activating the market size sector can change the quantitative characteristics of the window of opportunity, but not the qualitative behavior. For instance, with more expansion of demand as prices drop, the window of opportunity lasts longer although the conditions that mark the opening and closing remain the same.

As the remarks throughout the paper indicate, the results reported here apply potentially to many industries. There are four prerequisites for a window of opportunity to be available. Figure 13 summarizes.

Technology has prospects for substantial improvement
Technology has major impact on firm's competitiveness
Technology expands scale of efficient production
Intermediate speed of penetration

Figure 13. Prerequisites for the Window of Opportunity

First, the technology must have prospects for major improvement. This must be taken relatively, for everything is improvable to some degree, but if there is no need to worry about large improvements in later models, one can convert to a new technology whenever it appears cost-effective. For example, few people would postpone buying a car to wait for next year's models--we simply don't expect enough improvement to outweigh the inconvenience of postponement.

Second, the technology must have a major impact on the firm's competitive performance, otherwise there will be no overcapacity and profit squeeze. So, for example, architectural or engineering firms using CAD should show very similar dynamics. Note that price is not the only competitive variable; CAD/CAM is catching on very quickly among automobile manufacturers, not because they gain a significant price advantage from digital designing, but because CAD/CAM offers much more timely updating of designs. By contrast, there seems to be no danger of widespread overcapacity for word-processing users. Most firms do not accrue any major competitive advantage by converting to electronic word processing; the conversion decision is a simple cost/benefit decision with relatively little impact on the overall performance of most firms.

Third, the technology must expand the scale of production. This can be a requirement either of the technology or of labor and business practices: converting to a new technology must increase the amount of production desired by firms (otherwise conversions will reduce the number

of employees rather than produce overcapacity). When AT&T converted to electromechanical switching during the 1930s and 1940s, the conversion did not produce overcapacity; the switchboard operators were gradually discharged. Similarly today, word-processing machines are reducing the need for word-processing people, rather than producing overcapacity. But for lithographic setup shops, the purchase of a single electronic color system (ECS) has the potential to add productive capacity in excess of the firm's total production; no discharge of traditional craftsmen is large enough to counterbalance the excess capacity caused by conversion to ECS. In an industry with small firms and powerful technologies, conversion produces overcapacity and the conditions for a shakeout. (This effect can be mitigated to some extent if the drop in prices causes a large increase in demand. The market size sector can simulate these dynamics, although it is inactive for the simulations here.)

In some industries, switching to new technologies produces overcapacity simply because the equipment embodying the older technology remains operational; it is not modernized but added to. The U.S. steel industry, for example, has responded to Japanese and other foreign competition by building new facilities that are as modern and efficient as any plant in the world. But the old plants, many antiquated, still exist and contribute to worldwide overcapacity. Companies have few options to escape this situation. Retrofitting old plants with new technologies tends to be more expensive than building "greenfield" plants; shutting down or dismantling older facilities causes poor financial performance, at least in the short term.

Fourth and finally, to create a window of opportunity, a technology must not penetrate its user market very rapidly (two months) or very slowly (many decades). If an industry adopts a new technology all at once, the window of opportunity is gone, but then so is the question of when to convert. By analogy, no child obtained any advantage for very long by being a trend setter with hula hoops, because everyone had one shortly. At

the other end of the spectrum, if so few firms convert that the technology never takes off (even if it is ultimately improvable), there is no shakeout, no window of opportunity, and no uncertainty about timing. There is ample time to decide, and firms will use the technology when it is cost-effective; so there is no window of opportunity that opens and closes.

The window of opportunity dynamics seem to apply to a pleasingly diverse set of industries and technologies, and we look forward to applying this framework again. Yet it should be emphasized that the modeling effort achieved its principal goal, which was to improve the understanding by various clients of the issues surrounding the decision to convert to new technologies. The model has already been used as a medium of communication for discussing the future of the color printing industry with representatives of both lithographic setup shops and equipment makers. Moreover, a systematic review of the details of the firm sector has yielded several managerial guidelines for the conversion process itself. Although project results like "improvement of understanding" are certainly difficult to assess, the authors' subjective impressions are that the study contributed an enormous amount of clarity and structure to the situation, starting from an initial understanding that was little more than a loosely related tangle of concerns about the future.

ACKNOWLEDGEMENTS

The modeling project whose results are described here grew out of a class project [7] under the auspices the the MIT Corporate Research Program in System Dynamics, which was created by Professor John Morecroft [8]. Robert Lucadello performed part of the original modeling work. The work was supported both financially and epistemologically by David Goodstein and Gregory Van Buren of Inter/Consult. They have also extended the modeling in the direction of creating a user-friendly interface between the model and clients [9]. The original working versions of the model diagrams were created by David Kreutzer and Janet Gould with assistance from Scott Ewing on a Designer System donated to M.I.T. by Computervision Corporation and made available for use by Professor David Gossard. The final versions were drawn by Diane Leonard-Senge, and Andrew Plummer assisted with preparation and editing.

REFERENCES

[1] Lippman, Andrew B. and Nicholas Negroponte, Slides from the Arts and Media Technology Case Studies, Architecture Machine Group, Massachusetts Institute of Technology, 1983.

[2] Paich, Mark, "Managing the Transition Between Basic Production Technologies: A Case Study and Generic Lessons," 1982, Sloan School Working Paper 1386-82, M.I.T., Cambridge, Massachusetts.

[3] Graham, Alan K., "Software Design: Breaking the Bottleneck," IEEE Spectrum, March 1982, pp. 43-50.

[4] Roberts, Edward, Managerial Applications of System Dynamics, 1981, Cambridge, Massachusetts: The M.I.T. Press, pg. 3.

[5] Forrester, Jay W. Industrial Dynamics, 1961, Cambridge, Massachusetts: The MIT Press.

[6] Gould, Janet and David Kreutzer, "Interactive Computer Graphics Technologies for Representing System Dynamics Model Structure, Behavior, and Results," 1983, System Dynamics Group Working Paper D-3431, Sloan School of Management, M.I.T., Cambridge Massachusetts.

[7] Kreutzer, David P. and Robert Lucadello, "Strategies for Investing in Electronic Color," 1982, System Dynamics Group Working Paper D-3357, Sloan School of Management, M.I.T., Cambridge, Massachusetts.

[8] Morecroft, John D. W., "The System Dynamics Corporate Research Program: A Prospectus," 1983, System Dynamics Group Working Paper D-3245-9, Sloan School of Management, M.I.T., Cambridge, Massacusetts.

[9] Van Buren, Greg and David H. Goodstein, "Development of a Causal User Interface for Simulation Models," 1983, Inter/Consult, Technology Center, 21 Notre Dame Avenue, Cambridge, Massachusetts.

[*] Kreutzer, David P., "Documentation of the Electronic Color Systems Model," 1983, System Dynamics Group Working Paper D-3509, Sloan School of Management, M.I.T., Cambridge, Massachusetts.

Date Due